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The angular distribution of the D-D neutrons

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With 4 figures in the text

Introduction

In 1936 Kempton, Maasdorp, and Browne[1] were able to prove that neutrons and protons from the $D(d, n)$ and the $D(d, p)$ reactions showed a marked isotropic angular distribution, when the observations were converted to a coordinate system resting in the centre of mass of the particles. In the energy region below 0.5 Mev the angular distribution is represented by[2]

$$n'(\Theta') = n'(90)\,(1 + A(E)\cos^2\Theta'),$$

where $n'(\Theta')$ is the neuteron flux as measured in a direction forming the angle Θ' between the incident deutron and the emitted neutron in the c. m. s. coordinates.

The degree of anisotropy is determined by factor $A(E)$, which is strongly dependent on the deuteron energy E. The anisotropy of the proton emission has been extensively investigated[3, 4, 5] for deuteron energies below 0.5 Mev, and measurements into D–D neutrons have been published[6, 7, 8] for deuteron energies over 0.5 Mev; but as far as the author knows no investigations into the energy dependence of the neutron anisotropy in the low energy region have as yet been published. Due to both the experimental and theoretical importance of the D–D reaction[9, 10], an investigation of the neutron anisotropy in the low deuteron energy region seems to be interesting.

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[1] Kempton, Maasdorp, and Browne, Proc. Roy. Soc. A 157, 386, 1936.
[2] Konopinski and Teller, Phys. Rev. 73, 822, 1948.
[3] Huntoon, Ellett, Bayley, and Van Allen, Phys. Rev. 58, 97, 1940.
[4] Manning, Huntoon, Meyers, and Young, Phys. Rev. 61, 371, 1942.
[5] Bretcher, French, and Seidl, Phys. Rev. 73, 815, 1948.
[6] Bennet, Mandeville, and Richards, Phys. Rev. 69, 418, 1946.
[7] Freir, Lampi, Sleator, and Williams, Phys. Rev. 74, 1599, 1948.
[8] Hunter and Richards, Phys. Rev. 76, 1445, 1949.
[9] Konopinski and Teller, Loc. cit.
[10] Hanson, Taschek, and Williams, Rev. of Mod. Phys. 21, 635, 1949.

Experimental arrangements

The measurements are made with the neutron generator at the Physical Laboratory of Uppsala University[1, 2].

The separated D^+-beam hit a heavy-ice target. The neutron yield as a function of the deuteron energy was measured in five separate positions of the neutron counter, corresponding to five angles between the incident deuteron and the emitted neutron. The angle was varied between 0° and 90°, and the deuteron energy between 50 and 200 kev.

In order to receive as high a counting speed as possible, a BF_3-counter surrounded by a paraffin moderator was used. The counter was connected to a proportional amplifier and a scale of 128. The amplifier discriminator was properly biased to register the ionisation from the $n\,(B^{10}, \alpha)\,Li^7$ reaction only. The high counting speed made it possible to attain shorter runs of the acceleration tube so as to receive a better constancy of the tube parameters. The statistical error of the neutron counting was kept below 2.5 %.

There are certain difficulties connected with the neutron counting. The counter will register (a) neutrons from the target, and (b) scattered neutrons, as well as (c) neutrons released in other parts of the accelerating tube than the target. To measure the scattering, the target was replaced by a Ra–Be neutron source. The neutron flux of the source was assumed to be symmetrical. Measurements were made with the counter in all the positions used in the yield measurements. The difference in counting was less than 2 % in all counter positions. To avoid the neutrons not released in the target the yield was measured with a target of heavy ice as well as one of ordinary ice. The difference of the measurements is the neutron yield from the heavy-ice target. The counting speed when a target of ordinary ice was used was in all deutron energies less than 30 % of the counting speed when one of heavy ice was employed.

For the purpose of monitoring the conditions of the measurements, the ion current was measured. The measurements of the latter are described elsewhere[3], and are probably good to 2 %. The bombarding voltage is known within 1 %.[4]

Results

A semilogarithmic plot of the neutron yield as a function of $E^{-\frac{1}{2}}$ is shown in Fig. 1, where E is the deuteron energy. From the plot the neutron intensities of four different deutron energies were taken and converted to c. m. s. coordinates by means of the factor[5, 6]

$$g\,(\Theta) = \frac{\sin^2 \Theta}{\sin^2 \Theta'} \cos\,(\Theta' - \Theta),$$

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[1] G. Carlson, Ark. f. Fysik, Bd 2, nr 26.

[2] I. Bartholdson and G. Carlson, Ark. f. Fysik, Bd 2, nr 27.

[3] I. Bartholdson and G. Carlson, Loc. cit.

[4] G. Carlson, Loc. cit.

[5] Haxby, Allen, and Williams, Phys. Rev. 55, 140, 1939.

[6] Hanson, Taschek, and Williams, Loc. cit.

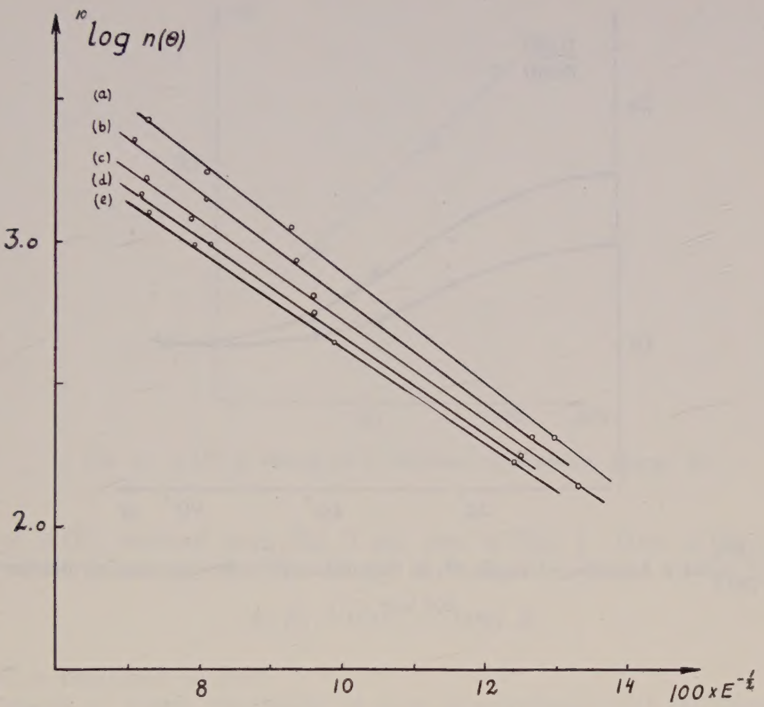

Fig. 1. A semilogarithmic plot of the neutron yield as a function of $E^{-\frac{1}{2}}$ with Θ equal to (*a*) 2°, (*b*) 32°, (*c*) 47°, (*d*) 60°, and (*e*) 90°.

Θ being the angle between the incident deuteron and the emitted neutron in the laboratory coordinates, and Θ' the corresponding angle in the c. m. s. coordinates. The $g(\Theta)$ factor corresponds to a conversion of the solid angle occupied by the neutron counter from the lab. to c. m. s. coordinates. The relation between Θ and Θ' is given by

$$\sin(\Theta' - \Theta) = \frac{V}{v} \sin \Theta,$$

where V is the velocity of the centre of mass, and v the neutron velocity in the c. m. s. coordinates. V is equal to half the deuteron velocity, and is computed from the accelerating voltage. From the Q-value of the $D(d, n)$ reaction and the accelerating voltage, v is calculated.[1]

The anisotropy is shown in Fig. 2, where $\frac{n'(\Theta')}{n'(90')}$ is plotted as a function of angle Θ', $n'(\Theta')$ being the neutron intensity as measured in the direction Θ' in c. m. s. coordinates. $A(E)$ is in the case of different deuteron energies taken from Fig. 3. In the figure, $\frac{n'(\Theta')}{n'(90')} - 1$ is shown as a function of $\cos^2 \Theta'$. The

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[1] Hanson, Taschek, and Williams, Loc. cit.

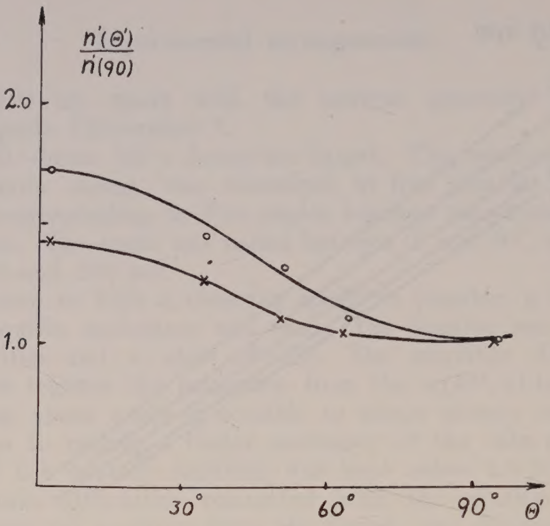

Fig. 2. $\frac{n'(\Theta')}{n'(90')}$ as a function of angle Θ' in two different deuteron energies, 100 kev (×) and 200 kev (○).

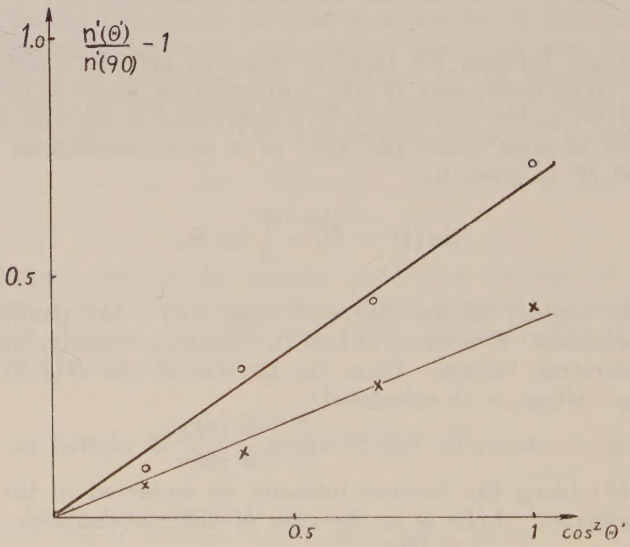

Fig. 3. $\frac{n'(\Theta')}{n'(90')} - 1$ as a function of $\cos^2 \Theta'$ in two different deuteron energies, 100 kev (×) and 200 kev (○).

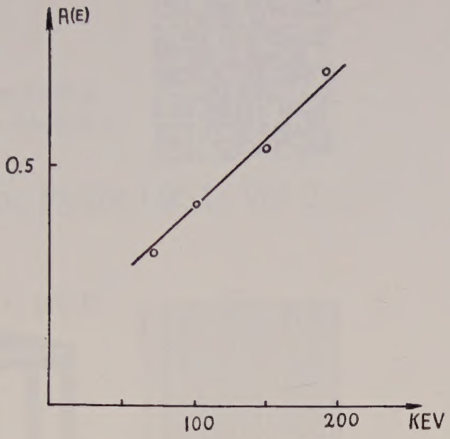

Fig. 4. $A(E)$ is shown as a function of deuteron energy E.

values of $A(E)$ received from Fig. 3 are seen in Fig. 4. Here $A(E)$ is plotted against deuteron energy E. The energy dependence is found to be

$$A(E) = 0.15 + 0.0027\, E,$$

where E is measured as kev.

This result is, within the limits of error, in accordance with the corresponding proton measurements.[1] This agreement indicates that, in the low deuteron energy range, the neutron angular anisotropy is mainly dependent on the Coulomb and centrifugal barriers of the incident particle[1, 2].

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[1] KONOPINSKI and TELLER, Lcc. cit.
[2] HUNTER and RICHARDS, Loc. cit.

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